A metric for comparing acoustic transmission loss curves

J. Paquin Fabre
Naval Research Laboratory
Code 7180
Stennis Space Center, MS 39529 USA

Abstract- **A metric is presented for quantifying the difference between two acoustic transmission loss curves. This allows a fast, but more importantly, consistent way to determine how well two underwater acoustic transmission loss curves compare in terms of their end use. Two methods are proposed for different applications, the first involves comparing only the curves themselves and the second involves use of a figure of merit to compare the curves as they apply to an end performance estimate.**

I. Introduction

In the discipline of underwater acoustics, it is frequently necessary to determine how well two transmission loss (TL) curves (model or data) compare. If there are few curves, this can be done graphically, but this process can be subjective. Quantitative comparisons can be made by subtracting the curves, but because TL is in log space (decibels or dB), high differences in high values of loss are not as critical as high differences in values of low loss. This can be accounted for by weighting the TL. Additionally, due to phase variations, the curves may contain a range offset that is acceptable in some cases. For applications, performance parameters (coverage, probability of detection or signal excess) can be compared using a figure of merit (FOM). The intent of this paper is to propose a fast, consistent metric to evaluate the difference between two curves, so that a single number can be provided for analysis of the comparison(s). This method can be used to compare any two TL curves, from models or data.

II. Method

A. TL Curve Comparison

In order to prepare the data for comparison, a number of checks are completed. All ranges must be unique, and the curves are adjusted so that the maximum ranges match (the shorter value). The curves are then interpolated to the same range grid in intensity space and then converted back to decibels (dB).

The first component of the metric considers the magnitude of the difference between the two TL curves at each range, weighted and normalized by the sum of the weights over all ranges,

$$TL_1^{diff} = \frac{\sum_r \left| TL_2(r) - TL_1(r) \right| w(r)}{\sum_r w(r)} \tag{1}$$

Where the weights, *w*, suggested by Zingarelli [1], consider that losses greater than 110 dB (though this can be modified) are not included, losses between 60 and 110 dB are weighted as below and losses less than 60 dB are considered directly.

$w = 1$	$TL \leq 60$
$w = (110 - TL)/50$	$60 < TL \leq 110$
$w = 0$	$TL > 110$

The weighted differences (TL_1^{diff} from equation 1) are then assigned a value between 0 and 100 based on. This assigns a loss between 0 and 3 dB a high score (90s), and slightly linearly rates the remaining scores less, where anything greater than or equal to 20 dB loss results in a score or metric value of 0. These values can be modified if higher differences can be tolerated and therefore scored differently. However, for consistency it is recommended that these values be set once and not modified.

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14. ABSTRACT
A metric is presented for quantifying the difference between two acoustic transmission loss curves. This allows a fast, but more importantly, consistent way to determine how well two underwater acoustic transmission loss curves compare in terms of their end use. Two methods are proposed for different applications, the first involves comparing only the curves themselves and the second involves use of a figure of merit to compare the curves as they apply to an end performance estimate.

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TL is often run to the range of interest and the values at that range are used for computations, this portion of the metric adds that consideration. The second component of the metric then considers the mean magnitude difference in the last 4% of the range. For example, for a 50km run, the mean difference is computed over the last 2km.

$$TL_2^{diff} = mean\left|TL_2(r) - TL_1(r)\right| \qquad (2)$$
$$r = r_{r\max} - .04 * r_{\max} \quad to \quad r_{\max}$$

The weighted differences (TL_2^{diff} from equation 2) are then assigned a value between 0 and 100 based on .

A standard way of comparing two data curves is to consider their correlation coefficient (e.g. [3]). The third component of the metric is the correlation coefficient normalized between 0 and 100 where negative correlations score 0.

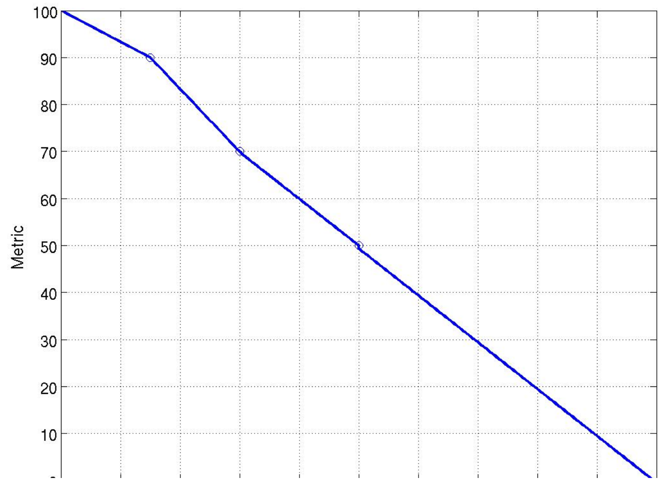

Figure 1. Metric values for scoring TL differences.

If only comparing the two curves, the final difference metric is then the average of these three metrics.

$$M_{curve} = \frac{1}{3}\sum_{i=1,3} M(TL_i^{diff}) \qquad (3)$$

Where $M(TL_i^{diff})$ is the metric assigned based on the three (*i*=1,3) TL^{diff} values as described above.

B. TL Thresholded Comparison

Many applications require the computation of a performance parameter, such as signal excess, area coverage or probability of detection. A simplified way to compute such values applies a figure of merit (FOM) as a threshold, where values above the FOM are considered detectable. Therefore the previous metric is extended for those cases. If a FOM is entered as 0, equation 4 determines the TL difference metric. Otherwise a range coverage difference and a near-continuous range difference are computed and contribute to the TL difference metric.

Signal excess (SE) is the amount of signal that is detectable. Acoustic coverage (e.g. [4]) can be used to show the amount of area a sensor will cover. Here, coverage is computed using only range, instead of area, and is weighted by the energy above the FOM to account for better detection capability with more energy available to detect. This range coverage energy is then converted to a percent coverage by dividing by the maximum range. The magnitude of the differences between the percent covered is computed and weighted between 0 and 100 for the fourth contribution to the metric.

Detection ranges are often computed from TL and FOM, so the last contribution to the difference metric is a near-continuous detection range. That is, the range to which there is positive signal excess, allowing for very short (1 range step) duration dips below the FOM. A percentage is then computed by normalizing the detection range by the maximum range. This is then normalized between 0 and 100 to provide the fifth and final contribution to the TL difference metric.

$$M_{total} = \frac{1}{5}\left(\sum_{i=1,3} M(TL_i^{diff}) + M_{r\,\mathrm{cov}} + M_{DR}\right) \qquad (4)$$

Where M_{rcov} is the range coverage percentage difference metric and the M_{DR} is the detection range difference metric.

III. RESULTS

This metric has been applied to many TL curve pairs. A number of examples are given here. Figure 2 through Figure 6 show transmission loss at 3 kHz, computed from the same environmental track, but one is high resolution in the sound speed and the other has been smoothed. This case is meant to emulate the differences in using a measured sound speed (high resolution) and a modeled sound speed, which tends to be smoother. The results are shown for a shallow source in ~1000 m of water with 5 receiver depths, 50m, 100m, 150m, 200m and 250m, respectively. The metrics are computed using equation (6) with a FOM = 75 dB.

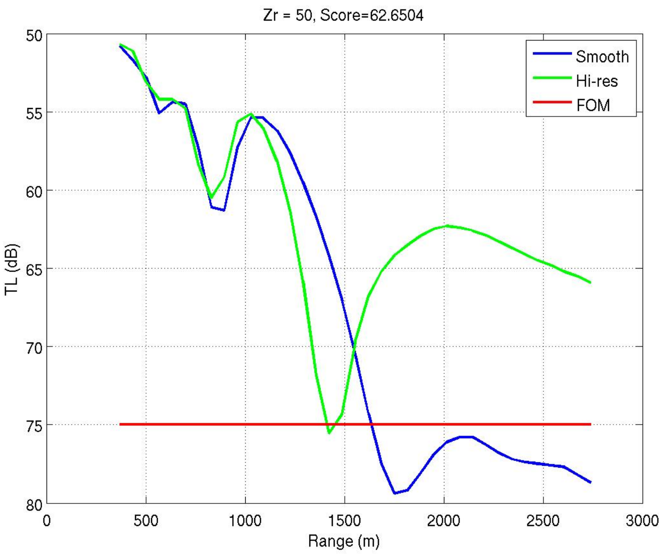

Figure 3. Comparison of TL at a receiver depth of 50 computed using smooth and high resolution sound speed with an 83 dB FOM.

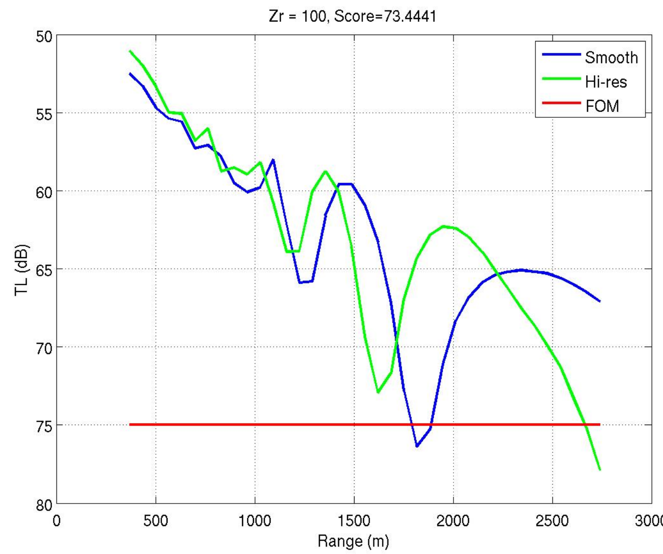

Figure 3. Comparison of TL at a receiver depth of 100 computed using smooth and high resolution sound speed with an 83 dB FOM.

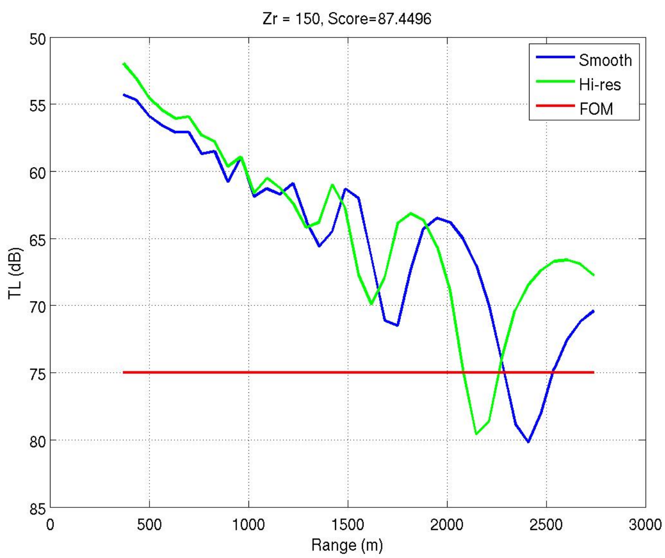

Figure 5. Comparison of TL at a receiver depth of 150 computed using smooth and high resolution sound speed with an 83 dB FOM.

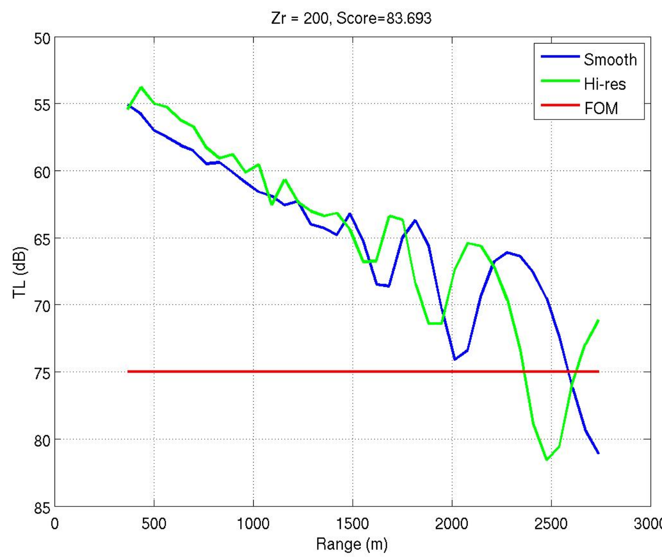

Figure 5. Comparison of TL at a receiver depth of 200 computed using smooth and high resolution sound speed with an 83 dB FOM.

Table 1 summarizes the score contributions for Figure 2 through Figure 6. The total metric from all 5 contributions is the first column, the metric if only the first 3 contributions were considered (Equation 3) is the next, followed by the individual contributions in the order that they were discussed. If one were to rank the curves by eye, in terms of "goodness" of comparison, the receiver depth of 150 would be the best and as expected, that curve comparison gave the highest score.

The next case shows a deep water track for 3kHz, run with range dependent sound speed and sediment compared to the same radial with range independent sound speed and sediment. The source is near 100m and the receiver is at 50m. The FOM used was 83 dB for the first case () and 110 dB for the second. This shows the difference in the metric using a FOM, the contribution from the first 3 terms is the same for both cases. These two cases still have very similar metric values, because the area available for detection, while at different ranges, is approximately the same; and the near continuous range is nearly the same for both. If lower resolution curves were used in this case, the results could have been vastly different. Therefore, it is recommended that range averaged results, which more closely reflect what would be measured, be used in this metric.

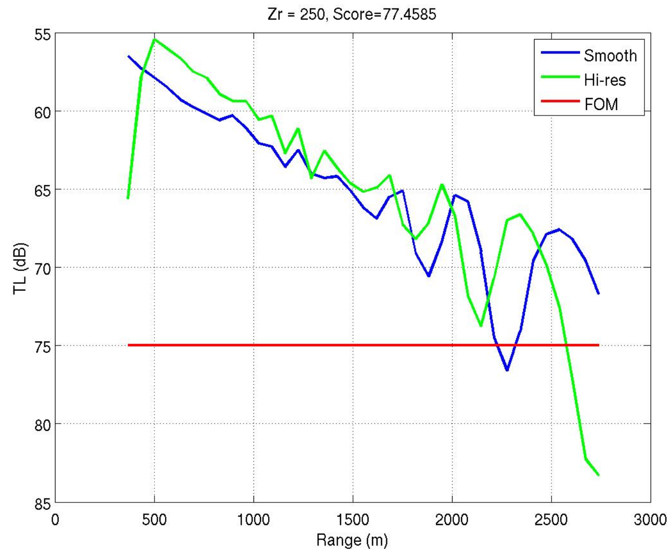

Figure 6. Comparison of TL at a receiver depth of 250 computed using smooth and high resolution sound speed with an 83 dB FOM.

TABLE 1

SUMMARY OF SCORES FOR TEST CASES SHOWN IN FIGURES 2-6

Figure / Case	Total (Eq 6)	No FOM (Eq 3)	Wtd Diff (Eq 1)	Diff at Rng (Eq 2)	Correlation	Coverage Energy	Det Rng
2 Zr = 50 m, FOM 75	62.7	53.0	61.9	35.9	61.2	95.1	59.1
3 Zr = 100 m, FOM 75	73.4	66.2	84.7	51.0	62.9	99.9	68.8
4 Zr = 150 m, FOM 75	87.4	81.9	87.3	86.7	71.7	98.7	92.8
5 Zr = 200 m, FOM 75	83.7	75.3	90.0	58.9	77.1	99.7	92.8
6 Zr = 250 m, FOM 75	77.5	66.7	90.0	38.9	71.3	99.1	88.0

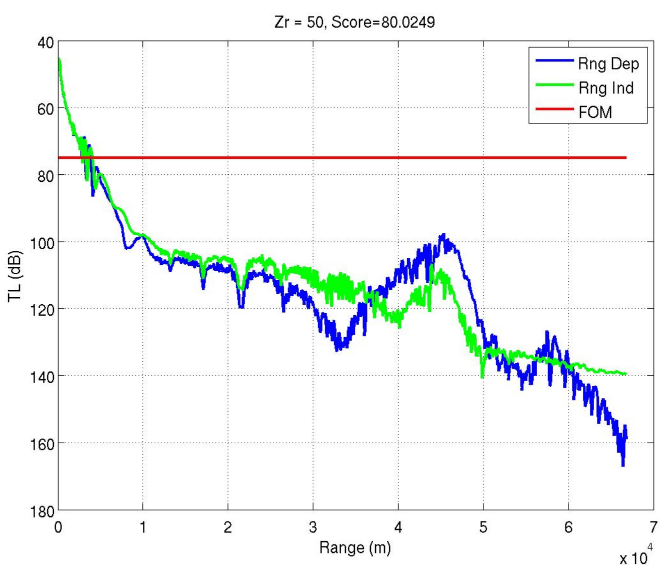

Figure 8. Deep water range dependent versus range independent with FOM = 83 dB, near continuous range near .5km.

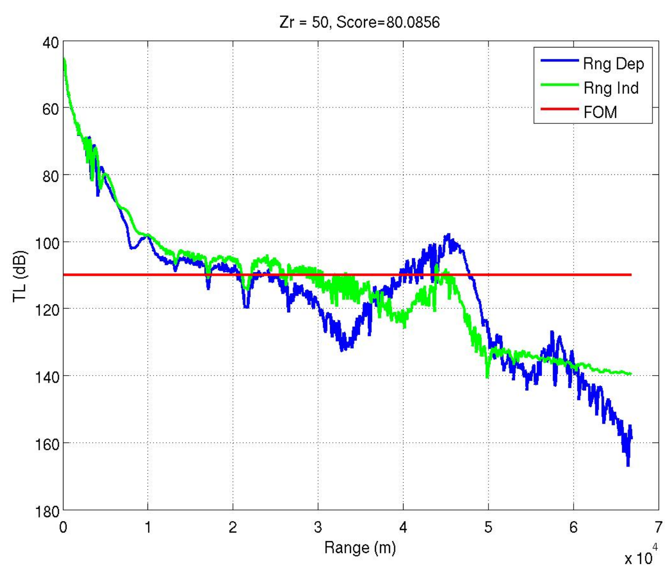

Figure 8. Same case as Figure 8 using a FOM of 110 dB, near continuous range near 2 km.

The table below summarizes the metric results for Figure 7 and Figure 8.

TABLE 2
SUMMARY OF SCORES FOR TEST CASES SHOWN IN FIGURES 7-8

Figure / Case	Total (Eq 6)	No FOM (Eq 3)	Wtd Diff (Eq 1)	Diff at Rng (Eq 2)	Correlation	Coverage Energy	Det Rng
7 Zr = 50 m, FOM 83	80.0	66.9	92.7	15.9	92.2	99.9	99.3
8 Zr = 50 m, FOM 110	80.1	66.9	92.7	15.9	92.2	99.8	99.8

The next cases show predictions for which the surface loss was included using climatological wind speed compared to no wind speed (flat surface) for two FOMs (Figure 9 and Figure 10) and to spherical spreading (20 $\log_{10}$ R) (**Error! Reference source not found.**) for water approximately 2000m deep, 800 Hz. The metric is fairly low due to the greater than 20 dB differences at the selected range (Rmax). The metric components are shown in Table 3.

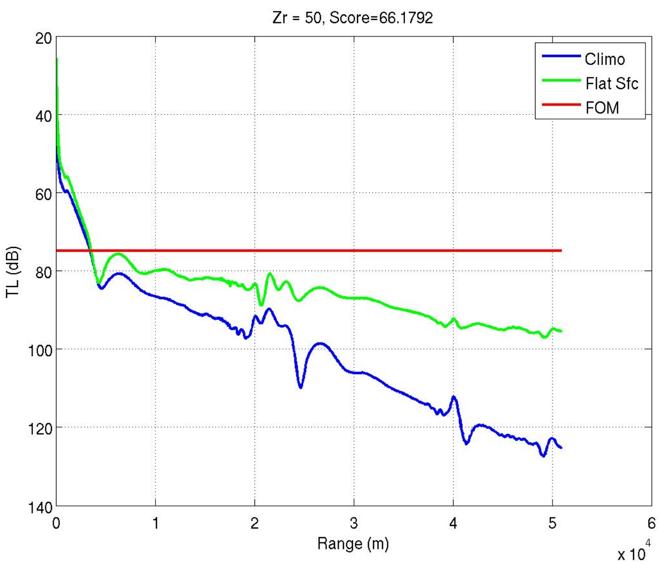

Figure 9. Range dependent climatological wind speed compared to flat surface with FOM = 83 dB.

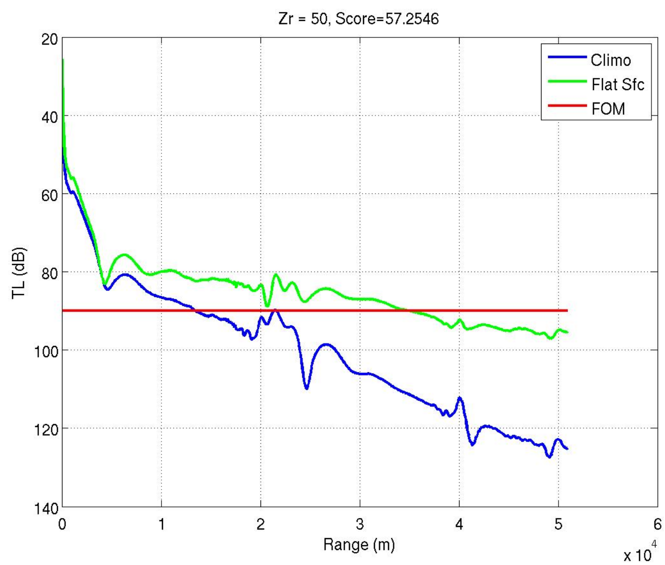

Figure 10. Range dependent climatological wind speed compared to flat surface with FOM = 90 dB.

TABLE 3
SUMMARY OF SCORES FOR TEST CASES SHOWN IN FIGURES 9-11

Figure / Case	Total (Eq 6)	No FOM (Eq 3)	Wtd Diff (Eq 1)	Diff at Rng (Eq 2)	Correlation	Coverage Energy	Det Rng
9 Zr = 50 m, FOM 83	66.2	43.7	35.9	0.0	95.3	99.8	99.8
10 Zr = 50 m, FOM 90	57.2	43.7	35.9	0.0	95.3	97.5	57.6
11 Zr=50 m, FOM 90	58.5	43.3	36.9	0.0	93.0	98.0	64.4

IV. DISCUSSION

An automated metric to quantify the difference between to acoustic TL curves has been developed. This sort of comparison is difficult and as indicated, can produce different results for different applications. The technique presented here is specific to underwater acoustic TL curves in dB and considers the crossing of a threshold (FOM). The algorithm has been weighted so that high scores are near 100 and low scores are near 0. Weights can be adjusted to "calibrate" the algorithm. This algorithm is meant to process many TL curves so that the scores can be examined and more close analysis can be done on a case by case basis.

Other contributions to the metric were considered, but it seemed to be more robust to keep the number of contributors low.

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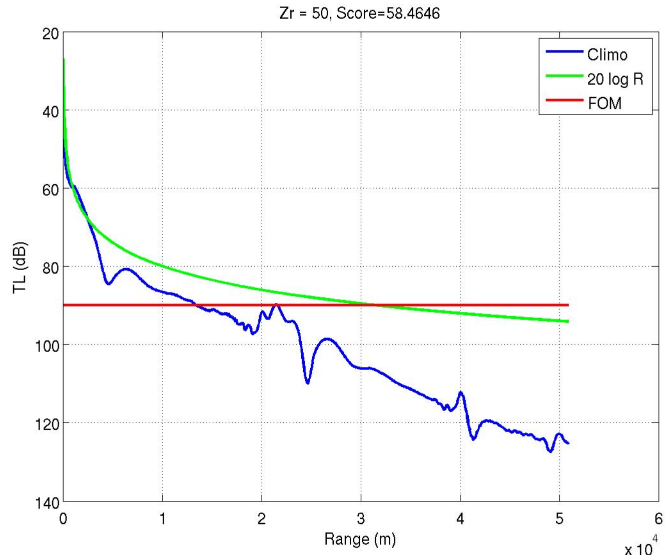

Figure 11. Range dependent climatological wind speed compared to spherical spreading with FOM = 90.